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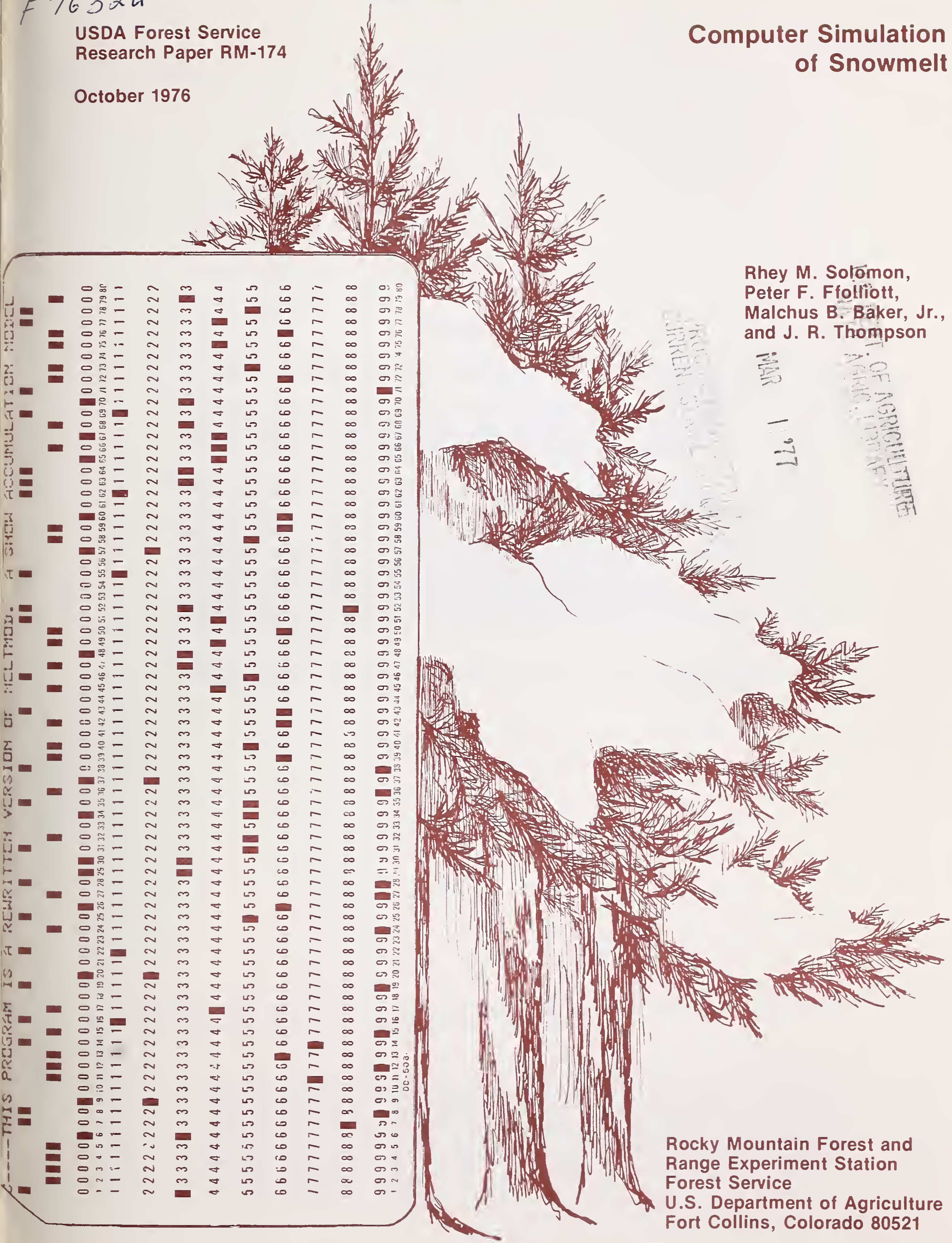
October 1976

Computer Simulation of Snowmelt



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Abstract

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A modification of a previously developed computer model of snowmelt provides for modeling intermittent snowpacks, and is believed to be a more generalized model than the original program. The modified program SNOWMELT is dependent on four daily input variables, maximum and minimum temperatures, precipitation, and shortwave radiation or percent cloud cover. Initializing the model requires limited knowledge of local watershed and snowpack parameters. Model verification on seven experimental watersheds in Arizona proved satisfactory.

Keywords: Computer models, intermittent snowpacks, simulation analysis, snowmelt.

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Introduction

Researchers have studied snow in various ways to more fully understand processes involved in snow accumulation, melt, and its resultant runoff. To investigate interrelationships of the many variables affecting snowmelt would require large amounts of data, many parameters, and numerous calculations. To circumvent many of these problems, computer models have been synthesized that are designed to simulate the melting of snowpacks (Leaf and Brink 1973a, 1973b; U.S. Army, Corps of Engineers 1972).

For computer models to be of practical use, the input variables required for the models should be easily obtained, and the models must have utility for the land manager.

Leaf and Brink (1973a) developed a model (MELTMOD) intended to be used with input variables sensitive to vegetation manipulations. MELTMOD was developed for Colorado subalpine forests, with verification data collected from the 667-acre Deadhorse Creek watershed on the Fraser Experimental Forest (Leaf 1971, Leaf and Brink 1972). Thus, the model was limited in its scope of possible melt regimes, and by snowpack conditions that might be encountered in other areas of the country.

MELTMOD was evaluated as a model for estimating daily and weekly snowmelt rates for snowpack conditions found in the Southwest, and more specifically as a tool for characterizing runoff efficiencies of small Arizona watersheds (Solomon et al. 1975). MELTMOD was found to be unsatisfactory, however, principally because of three shortcomings: the inability of the model to respond quickly to alternate freezing and melting patterns during the accumulation and melt phases; the model tended to keep the snowpack excessively "cold" during the accumulation phase; and some of the input variables necessary for the model, daily solar radiation in particular, were not always available. Because of these inadequacies in modeling intermittent snowpacks, MELTMOD was modified to account for intermittent snowpack conditions which are often found in the Southwest. The intent of this modification was to produce a general snowmelt model, applicable to simulating both continuous and intermittent snowpacks. However, all tests of the modified model to date have pertained to intermittent snowpacks, and no attempt has yet been made to verify the new model's applicability for simulating continuous snowpacks.

Program Description

Basically, the modified computer model SNOWMELT simulates: winter snow accumulation; energy balance; snowpack conditions; and resultant snowmelt, with a sensitivity to slope, aspect, temperature, shortwave radiation, and forest cover density. SNOWMELT simulates the same basic processes that were common to MELTMOD: the segregation of precipitation into the snow and rain components; the melting process, including the energy budget; and snowpack conditions in terms of energy level and free water requirements. Modifications of MELTMOD were necessary, however, to better simulate the intermittent snowpacks common in Arizona. Many of the subroutines in the MELTMOD model have not been altered, and their flow paths will not be discussed; subroutines that have been eliminated, added, or modified will be reviewed.[3]

Five alterations of MELTMOD were necessary: segregation of rain and snow inputs, synthesis of solar radiation data, alteration of snowpack radiating temperature, design of a thermal diffusion technique, and an accounting for areal extent during snowpack ablation.

The modified program SNOWMELT is dependent on only four daily input variables: (1) maximum temperature, (2) minimum temperature, (3) precipitation, and (4) shortwave radiation or percent cloud cover. In addition, the following initializing values are required: (1) initial snowpack temperature, (2) a solar radiation transmissivity coefficient, (3) forest cover density, (4) initial snowpack water equivalent, (5) a threshold temperature value for use in calculating snowpack reflectivity, (6) mean slope and aspect of the watershed, (7) latitude, (8) an atmospheric absorption coefficient, and (9) a time interval for hour angle changes in subroutine SOLAR. If daily solar radiation values are available, they are corrected for slope and aspect prior to use in SNOWMELT. Therefore, variables (6), (7), (8), and (9) are not necessary in SOLAR, as they are only used in calculating a daily insolation incident upon the forest canopy.

[3]*All subroutines have been programed for the CDC 6400 computer at the University of Arizona, Tucson.*

Segregating Precipitation Into Rain and Snow Components

Separation of precipitation into snow and rain components is one of the first steps in the flow of the model (fig. 1). The original MELTMOD program used the daily minimum temperature as an index in segregating precipitation into snow, rain, or mixed events. If the daily minimum temperature fell below 32°F **or** the daily maximum temperature was less than 35°F, any precipitation fell as snow. We altered MELTMOD guidelines to consider precipitation as all snow if the maximum temperature drops below 40°F **and** the minimum daily temperature never exceeds 35°F. Criteria for mixed snow and rain events are altered only slightly. Precipitation falls as rain when the minimum temperature exceeds 35°F; mixed rain and snow falls when the minimum temperature drops below 35°F, **and** the maximum temperature exceeds 40°F. The mixed-event partitioning is performed through the same equation as used in MELTMOD (Leaf and Brink 1973a). The reasons for these changes came from examination of winter-precipitation data from Flagstaff, Arizona (Beschta 1974).

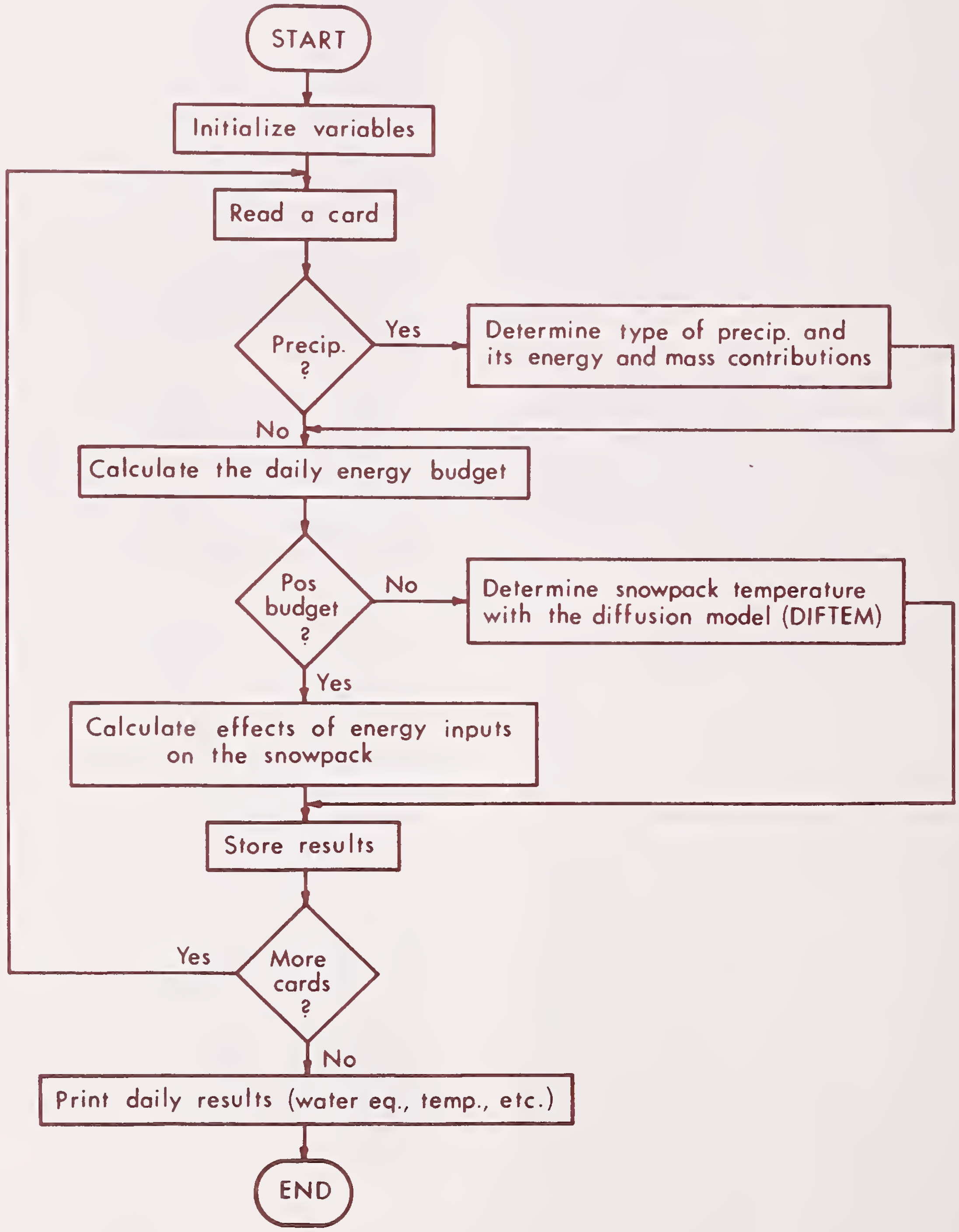

Figure 1.—General flow chart for program SNOWMELT.

Synthesis of Solar Radiation Data

Lack of daily solar radiation data prompted the incorporation of subroutines SOLAR and CLOUD into the program (see appendix).

Subroutine SOLAR computes potential daily solar insolation inputs for uniform increments of time, routes the insolation through the atmosphere, and corrects for slope and aspect. Incremental values are then summed to arrive at total insolation for a day (fig. 2).

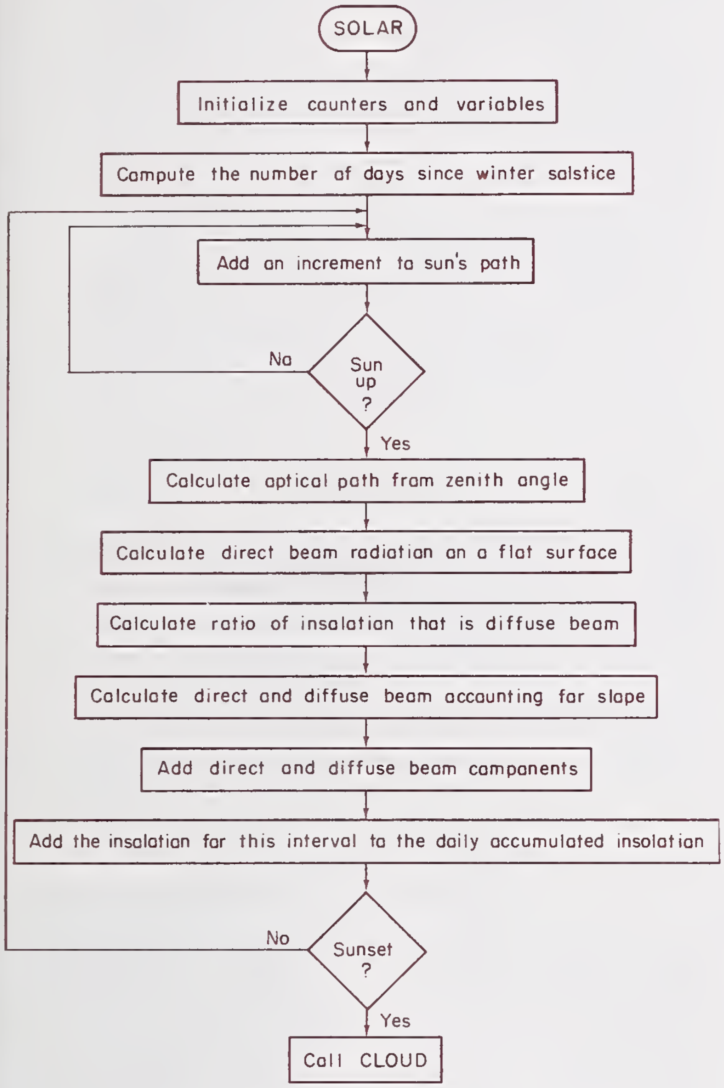

Figure 2.—Flow chart for subroutine SOLAR.

In this subroutine, direct beam solar insolation is obtained from equations presented by Frank and Lee (1966). These values are then routed through the atmosphere by an experimentally determined "extinction" coefficient. For Arizona conditions, this coefficient was found to be 0.13. Diffuse-beam solar insolation is determined from knowledge of solar altitude and direct-beam solar insolation by equations empirically derived from tables given by Reifsnyder and Lull (1965). A cloudless atmosphere is assumed.

Potential daily solar insolation is calculated every fifth day, since changes over a 5-day period are small.

Once a method for determining values for clear days was derived, some adjustment was necessary for cloudy days (subroutine CLOUD). An equation presented by Gates (1962), using mean cloud cover and a coefficient dependent on latitude, proved to be satisfactory:

$$Q = Q_0[1 - (1-K)C]$$

where:

Q_0 = total energy received without accounting for cloud cover;

K = a cloud cover parameter which is a function of latitude, given a value 0.38 at 30°, 0.41 at 40°, and 0.42 at 50°; and

C = average daily proportion of clouded to clear skies.

The cloud coefficients (K) were increased slightly from those shown by Gates because the equation tends to overestimate radiation for days with considerable cloud cover and underestimate for days with 50 to 70 percent cloud cover. Testing calculated values against 3 months of Flagstaff source data (January through March 1974) yielded an average daily value that was within 96 percent of the actual daily insolation and had a correlation coefficient of 0.87.

Snowpack Radiating Temperature

When a caloric deficit existed in MELTMOD (a snowpack below 0°C), the radiating temperature of the snowpack was made equal to the average ambient air temperature or 0°C, whichever was less. If there was no caloric deficit, the radiating temperature was made equal to the minimum air temperature or 0°C, whichever was less.

Changing the radiating temperature with snowpack conditions was necessary because of Colorado snowpack conditions. In Colorado, snowpacks normally increase in water content throughout the accumulation phase, with little or no melting (Leaf and Brink 1973a). Therefore, to keep the pack "cold" during the accumulation phase, thermal exchanges were controlled by a diffusion model. By using average ambient air temperature, the snowpack remained below 0°C until the melt season, at which time the model could be reinitialized by making the snowpack temperature 0°C. This is satisfactory for an area with distinct accumulation and melt season, but where periods of melt and accumulation alternate throughout the winter, as in Arizona, this approach is inadequate. Therefore, the radiating snowpack temperature was altered to allow only the minimum air temperature or 0°C, whichever was less, to be used as the radiating snowpack temperature.

Thermal Diffusion Subroutine

MELTMOD used a modified energy budget during periods of negative energy inputs. The routines controlling the use of the thermal diffusion model, principally DIFMOD, LINK, and RDPACK, were designed to control the snowpack temperature during the winter months when energy losses from the snowpack kept its temperature below 0°C. Additionally, the DIFMOD routine was only mathematically stable for snowpacks greater than 4.7 inches in depth. As a result, all three subroutines were discarded and a single subroutine (DIFTEM) was written for Arizona conditions. A flow chart of DIFTEM is shown in figure 3, and the subroutine is given in the appendix. A central differencing technique (Carnahan et al. 1969) was modified and adjusted to program SNOWMELT.

In the forward differencing procedure used by Leaf and Brink (1973a) in the development of MELTMOD, the value of $u_{i,j}$ is dependent upon $u_{i-1,j-1}$, $u_{i,j-1}$, and $u_{i+1,j-1}$ (fig. 4). Only those values of u within the pyramidal area A can have any influence on the value of $u_{i,j}$, whereas it is known that points in time earlier than t_j in area B also influence the value of $u_{i,j}$. In the implicit central differencing method we use, values of $u_{i,j}$ are evaluated at the advanced point in time t_{j+1} instead of t_j, as in the forward differencing procedure. This provides a wider base from which $u_{i,j}$ can be estimated.

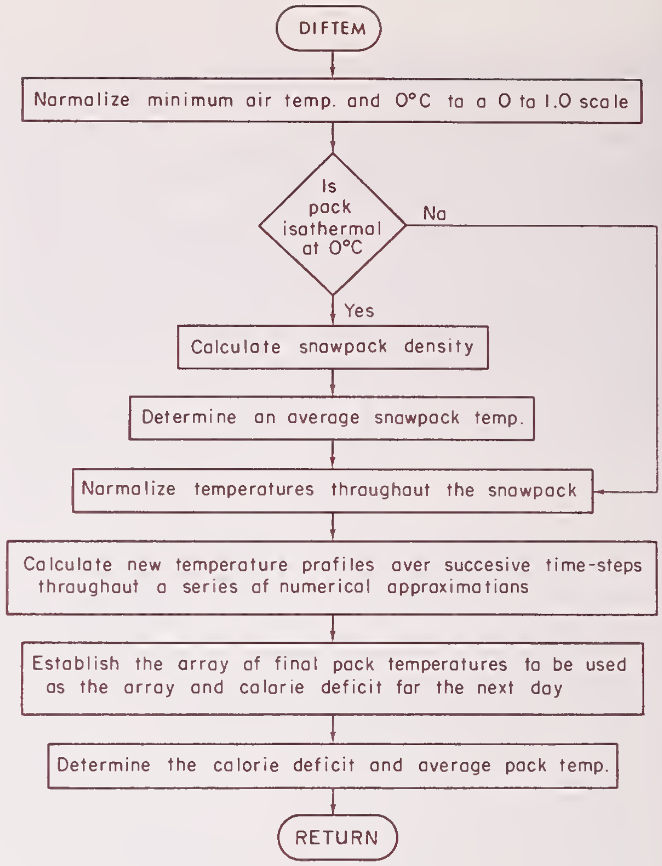

Figure 3.—Flow chart for subroutine DIFTEM.

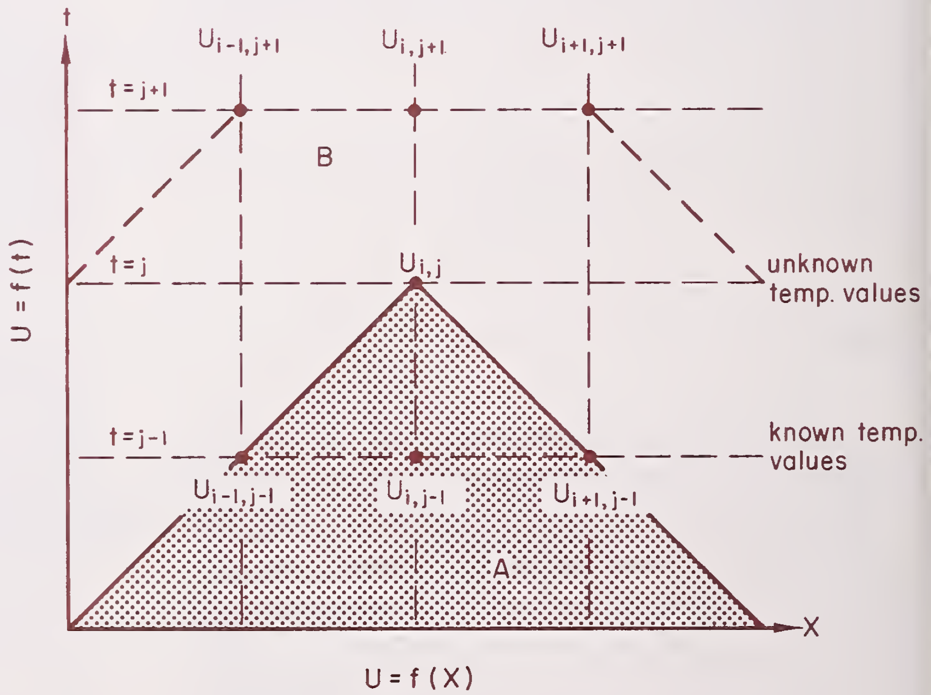

Figure 4.—Implicit central differencing method used in SNOWMELT.

Snowpack Conditions

Because snowpack ablation and areal depletion are not uniform throughout a forest, snow cover becomes discontinuous toward the end of the melt season (Brown and Dunford 1956, Leaf 1971). The original MELTMOD model did not account for this phenomenon, and as a result synthesized snowpack ablation rates were often excessive near the end of the melt season; 100 percent ablation was indicated before the end of generated runoff.

Snowpack water-equivalent measurements taken on small experimental watersheds in Arizona were utilized in determining snowpack cover percent as a function of mean watershed snowpack water-equivalent. For each sampling date, the number of sample points with no snow were ratioed to the total points surveyed, and the mean snowpack water-equivalents were calculated for that date. Graphical analysis of the data revealed that only snowpack water-equivalents under 3 inches showed deviation from 100 percent snow cover. Through regression analysis, 27 snowpack water-equivalent measurements were related to their corresponding percentages of snow cover. The correlation coefficient for the following equation was 0.93:

$$\text{percent cover} = 31.9 \text{ (snowpack water-equivalent)}$$

This equation is only used for snowpacks containing 3 inches or less of water. Therefore, when the mean watershed snowpack water-equivalent is below 3 inches, the calculated melt is reduced by the percentage of area not covered by snow. This technique is one method of simulating observations made by other researchers (Gary and Coltharp 1967, Ffolliott and Hansen 1968, Leaf 1971).

Model Verification

The model was verified by processing source data collected from seven experimental watersheds ranging from 20 to 467 acres. These watersheds were located across Arizona to obtain an array of vegetative, physiographic, and climatic conditions found in the Southwest.

Watershed Descriptions

Beaver Creek watershed 15, an area of 163 acres, is located approximatey 20 miles south of Flagstaff. The forest overstory is predominantly ponderosa pine, with an intermixing of Gambel oak and alligator juniper. Soils are derived from volcanic parent materials; elevations range from 6,735 to 7,160 feet. Annual precipitation averages 28 inches, one-third of which comes during November through April. Principal drainage is toward the southeast.

Beaver Creek watershed 17, about 299 acres in size, is 2 miles southeast of watershed 15. Ponderosa pine dominates the forest overstory, although Gambel oak and alligator juniper occur in scattered clumps. Soils are derived from volcanics; elevations range from 6,830 to 7,200 feet. Principal drainage is toward the southwest.

Heber watersheds 1 and 2, approximately 20 and 28 acres, respectively, are located 13 miles southeast of Heber, Arizona. The primary forest overstory of both watersheds is ponderosa pine, with an intermixing of Gambel oak, Douglas-fir, and white fir. Soils are derived from alluvial parent materials; elevations range from 7,400 to 7,700 feet. Annual precipitation is approximately 22 inches, half of which comes during the winter. Both watersheds have principal drainage to the south.

Heber watersheds 3 and 4, 60 and 61 acres, respectively, are located 6 miles south of Heber, Arizona. Principal forest overstory species are ponderosa pine and Gambel oak, with an intermixing of alligator juniper. Soils are derived from sandstone parent materials; elevations range from 6,900 to 7,050 feet. Both watersheds drain toward the north, with annual precipitation patterns and amounts similar to the Heber watersheds 1 and 2.

The North Fork of Thomas Creek, a 467-acre watershed, is located 20 miles south of Alpine. The mixed conifer forest overstory is predominantly Douglas-fir, white fir, corkbark fir, Engelmann spruce, and quaking aspen on north slopes, with ponderosa pine and Gambel oak on south slopes. Soils are derived from basalt parent materials; elevations range from 8,400 to 9,150 feet. One primary stream channel traverses the watershed from southwest to northeast. Annual precipitation averages 27 inches, one-third of which comes during November through April.

Assessment of SNOWMELT

Two input variables used in SNOWMELT—transmissivity and forest cover density—were found to have a marked influence on net daily energy budgets. An alteration of as little as 1 percent in transmissivity can produce a change of 0.2 inch in predicted snowpack water equivalent by the end of the snowmelt season. Values of forest cover density also affect melt rates, but not to the same extent as transmissivity. Forest cover density also plays an important role in maintaining a "cold" snowpack during the seasonal accumulation phase. While transmissivity and forest cover density are the most important variables in simulating the melting of snowpacks, it should be noted that these are also the most difficult variables to estimate.

The use of the new subroutine for periods of negative energy links proved to be satisfactory in not

permitting the snowpack temperature to fall below -5°C for more than a 1- or 2-day period. It also allowed quick recovery of the snowpack to isothermal conditions during periods of positive energy inputs.

Difficulties were encountered in the use of extrapolated temperature, cloud cover, and precipitation data due to failure of equipment located near the watersheds. In some cases, data were extrapolated over 50 miles. During some of these periods, separation of precipitation into snow and rain components was believed to have been inaccurate.

It is difficult to statistically assess the "goodness" of any snowmelt prediction in time-series models because of serial dependence within the model (Chow 1964, Yevjevich 1972). Therefore, of the seasons modeled (13 seasons of record on seven watersheds), three synthesized snowmelt seasons are graphically presented in figure 5: (A) a season of "good" fit (watershed 17, 1969); (B) a season of "average" fit (watershed 15, 1968); and (C) a season depicting a "poor" fit (North Fork of Thomas Creek, 1973).

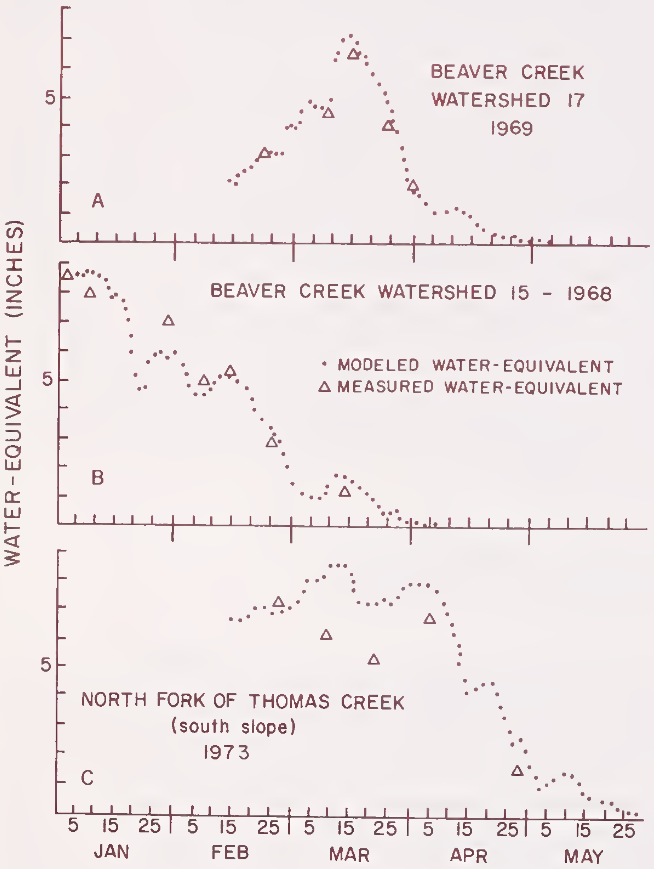

Figure 5.—Three seasons of snowmelt synthesized from program SNOWMELT.

Other peculiarities of the model were also noted. In the initial trials the North Fork of Thomas Creek was modeled as an entity, but program SNOWMELT failed to produce melt patterns corresponding to measured snowmelt water-equivalents. Therefore, because of its steep north- and south-facing slopes, the North Fork of Thomas Creek was divided into two contributing subwatersheds. Each area was then assessed as if it were a separate watershed. By this technique, melt regimes were generated that passed "near" points of observed snowmelt water-equivalent for each slope. It was concluded that watersheds having steep slopes facing north and south should be modeled as subwatersheds, with each slope assessed as a separate hydrologic unit. No modeling difficulties were encountered when watersheds containing steep slopes facing east-west (Heber watersheds 1 and 2) were modeled as one contributing unit.

Conclusions

SNOWMELT is believed to be a more generalized model than the original MELTMOD program, and it appears to have satisfactorily simulated intermittent snowpack conditions and snowmelt regimes. Initializing of the model requires only limited knowledge of local watershed and snowpack parameters. The only driving variables required for SNOWMELT are daily values of maximum and minimum air temperature, precipitation, and cloud cover or solar radiation. With some additional refinements (particularly in snow density predictions) and as data become available to more accurately characterize snow cover densities and transmissivities, SNOWMELT can be used over a wide range of snowpack regimes.

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APPENDIX

Subroutine SOLAR

```
THIS SUBROUTINE IS DESIGNED TO COMPUTE THE AMOUNT OF INCOMING
SOLAR RADIATION INCIDENT ON A GIVEN SURFACE DURING CLEAR SKY.
DICTIONARY
ABSK - ABSORPTION COEFFICIENT FOR THE ATMOSPHERE
ASPECT - AZIMUTH ANGLE, DEGREES  FROM NORTH
COSZ - COSINE OF ZENITH ANGLE(Z)
D - INCOMING DIFFUSE BEAM RADIATION, LYS/MIN
DELH - CHANGE IN HOUR ANGLE(H),MINUTES
DRATIO - RATIO OF DIFFUSE TO DIRECT BEAM RADIATION AS A FUNCTION
OF Z
H - HOUR ANGLE
HI - HOURS
H2 - MINUTES
OP - OPTICAL PATH
Q - INCOMING DIRECT BEAM RADIATION, LYS/MIN
QPOT - POTENTIAL DIRECT BEAM RADIATION ON A NORMAL SURFACE ABOVE
THE EARTH"S ATMOSPHERE, LYS/MIN
S - SOLAR CONSTANT, 2 LYS/MIN
SLOPE - SLOPE, PERCENT
XDEC - SOLAR DECLINATION
XLAT - LATITUDE, DEGREES
Z - ZENITH ANGLE
COMMON ACTDATE,ACTUAL(21),AVETEMC,AVETEMF,BASTEMF,ENGBAL,HOLDCAP
COMMON CALAIR,CALDEF,CALDRIE,CALSNOW,COVDEN,DATE,DATES(3),DEN
COMMON DENSITY,IFIRST,FOOTNOT(16),FREEWAT,IDATE(372),ISNOW,ITABLE
COMMON KOUNT,LASTUSD,LINES,OBSWEQV,RADIN,RADLWN,RADSWN,REFLECT
COMMON PACKTEM,PARTICE,PASTINT,PLOTOBS,PLOTWE,PRECIP,PREWEQV
COMMON SNOMELT,SOBSEQV(372),SPRECIP(372),SPREQV(372),SUBTITL(8)
COMMON TOTPREC,TITLE(8),THRSHLD,TEMPMIN,TEMPMAX,TCOEFF,USEMEAN
COMMON XMAX,USEPOT,SLOPE,ASPECT,XLAT,DELH,ABSK,CLCOV,ZAT,SUM4
COMMON KKPP,XLATE
INTEGER ACTDATE,DATE,DATES,FOOTNOT,PASTINT,PLOTOBS,PLOTWE,SUBTITL
INTEGER TITLE,USEMEAN,USEPOT
DIMENSION ZCLAN(12)
DATA ZCLAN/0.0,31.0,59.0,90.0,120.0,151.0,181.0,212.0,243.0,
+273.0,304.0,334.0/
PI = 3.14159265
S = 2.0
IF(KKPP.NE.5) GO TO 902
DELT = DELH
K = (24.*60.)/DELH
DELH = (DELH/60.)*15./180.*PI
XLATE = XLAT
XLAT = (XLAT/180)*PI
SLOPE = ATAN(SLOPE/100)
ASPECT =-(ASPECT/180.)*PI
902 KKPP = KKPP + 1
    IF(KKPP.LT.5) GO TO 103
    KKPP = 0
    H   = PI
    SUM1 =0.
    SUM2 =0.
    SUM3 =0.
    IDB =DATES(1)
    X = ZCLAN(IDB)
    DAY = DATES(2) + X
    IF(DAY.GE.355) GO TO 114
    DAY = DAY + 11
    GO TO 115
114 DAY = DAY - 355
115 XDEC = -.41015*(COS(DAY*PI/183))
    X3 = SIN(SLOPE)*COS(ASPECT)*COS(XLAT)+COS(SLOPE)*SIN(XLAT)
    X4 = ((1.-X3**2)**0.5)*COS(XDEC)
    X5 = ATAN((SIN(SLOPE)*SIN(ASPECT))/(COS(SLOPE)*COS(XLAT)-SIN(SLOPE
   .)*COS(ASPECT)*SIN(XLAT)))
    X6 = X3*SIN(XDEC)
    DO 100 I=1,K
    H = H-DELH
    COSZ = SIN(XLAT)*SIN(XDEC)+COS(XLAT)*COS(XDEC)*COS(H)
    IF(COSZ.LT.0.) GO TO 100
    Z=ACOS(COSZ)*(180./PI)
    QPOT=S*COSZ
    IF(Z.LT.60.) GO TO 10
    IF(Z.LT.70.) GO TO 11
    IF(Z.LT.80.) GO TO 12
    IF(Z.LT.85.) GO TO 13
    OP = -567+6.8*Z
    GO TO 20
 10 OP = 1.+0.0167*Z
    GO TO 20
 11 OP = -4.+0.1*Z
    GO TO 20
 12 OP = -18.+0.3*Z
    GO TO 20
 13 OP = -74.+Z
 20 Q      =QPOT*(1./(2.71828**(ABSK*OP)))
    IF(Z.LT.30.) GO TO 30
    IF(Z.LT.50.) GO TO 31
    IF(Z.LT.70.) GO TO 32
    IF(Z.LT.80.) GO TO 33
    DRATIO = -5.8+0.08*Z
    GO TO 40
```

```
30 DRATIO = D.12+0.D00667*Z
   GO TO 4D
31 DRATIO = 0.065+D.0025*Z
   GO TO 40
32 DRATIO = -0.135+0.0065*Z
   GO TO 40
33 DRATIO = -1.64+0.028*Z
40 D =          Q*DRATIO
   IF(SLOPE.EQ.D.) GO TO 50
   D       = D      *((PI-SLOPE)/PI)
   QPOT=S*(X4*COS(H+X5)+X6)
   IF(QPOT.GT.D.) GO TO 50
   QPOT = 0.
```

```
 5D Q       =QPOT*(1./(2.71828**(ABSK*OP)))
    QTOTAL = Q+D
    SA = 9D.-Z
 61 SUM1 = SUM1 + QPOT*DELT
    SUM2 = SUM2 + Q*DELT
    SUM3 = SUM3 + D*DELT
1DD CONTINUE
1D1 CONTINUE
    SUM4 = SUM2 + SUM3
103 CONTINUE
    CALL CLOUD
    RETURN
    END
```

Subroutine CLOUD

```
C     SUBROUTINE ACCOUNTS FOR PERCENT CLOUD COVFR IN CONVERTING POTENTIAL
C     SOLAR RADIATION TO A NET VALUE.
      COMMON ACTDATE,ACTUAL(21),AVETEMC,AVETEMF,BASTEMF,ENGBAL,HOLDCAP
      COMMON CALAIR,CALDEF,CALORIE,CALSNOW,COVDEN,DATE,DATES(3),DEN
      COMMON DENSITY,IFIRST,FOOTNOT(16),FREEWAT,IDATE(372),ISNOW,ITABLE
      COMMON KOUNT,LASTUSD,LINES,OBSWEQV,RADIN,RADLWN,RADSWN,REFLECT
      COMMON PACKTEM,PARTICE,PASTINT,PLOTOBS,PLOTWE,PRECIP,PREWEQV
      COMMON SNOMELT,SOBSEQV(372),SPRECIP(372),SPREQV(372),SUBTITL(8)
      COMMON TOTPREC,TITLE(8),THRSHLD,TEMPMIN,TEMPMAX,TCOEFF,USEMEAN
      COMMON XMAX,USEPOT,SLOPE,ASPECT,XLAT,DELH,ABSK,CLCOV,ZAT,SUM4
      COMMON KKPP,XLATE
      INTEGER ACTDATE,DATE,DATES,FOOTNOT,PASTINT,PLOTOBS,PLOTWE,SUBTITL
      INTEGER TITLE,USEMEAN,USEPOT
      DIMENSION COLATIT(7)
C       DICTIONARY
C     CLCOV - AVERAGE CLOUD COVEP FOR THE DAY
C     COLAT - A COEFFICIENT BASED ON LATITUDE.
      DATA COLATIT/.35,.34,.38,.41,.42,.44,.52/
   40 ZAT = XLATE/1D
      DO 10 M=2,7
      IF(ZAT.LE.M) GO TO 20
   10 CONTINUE
   20 N = M-1
      COLAT = (COLATIT(M)-COLATIT(N))*(ZAT-N)+COLATIT(N)
   3D RADIN = SUM4*(1.0-((1-COLAT)*CLCOV))
      RETURN
      END
```

Subroutine DIFTEM

```
C     THIS SUBROUTINE IS USED IN SIMULATING CHANGES IN SNOWPACK TEM-
C     PERATURES DURING PERIODS WHERE A CALORIE DEFICIT EXISTS.
C     DICTIONARY
C     DEN - DENSITY OF SNOWPACK
C     DEPTH - DEPTH OF SNOWPACK
C     DIFUS - DIFFUSIVITY OF THE SNOWPACK
C     TAU - TIME
C     DTAU - TIME INTERVAL
C     FF(I) - AN ARRAY USED IN SIMULATING SNOWPADK TEMPERATURES AT DIF-
C     FERENT DEPTHS.
C     TEMPK - NORMALIZED MINIMUM AIR TEMPERATURE
C     T(I) - TEMPERATURES WITHIN THE SNOWPACK
      COMMON ACTDATE,ACTUAL(21),AVETEMC,AVETEMF,BASTEMF,ENGBAL,HOLDCAP
      COMMON CALAIR,CALDEF,CALORIE,CALSNOW,COVDEN,DATE,DATES(3),DEN
      COMMON DENSITY,IFIRST,FOOTNOT(16),FREEWAT,IDATE(372),ISNOW,ITABLE
      COMMON KOUNT,LASTUSD,LINES,OBSWEQV,RADIN,RADLWN,RADSWN,REFLECT
      COMMON PACKTEM,PARTICE,PASTINT,PLOTOBS,PLOTWE,PRECIP,PREWEQV
      COMMON SNOMELT,SOBSEQV(372),SPRECIP(372),SPREQV(372),SUBTITL(8)
      COMMON TOTPREC,TITLE(8),THRSHLD,TEMPMIN,TEMPMAX,TCOEFF,USEMEAN
      COMMON XMAX,USEPOT,SLOPE,ASPECT,XLAT,DELH,ABSK,CLCOV,ZAT,SUM4
      COMMON KKPP,XLATE
      INTEGER ACTDATE,DATE,DATES,FOOTNOT,PASTINT,PLOTOBS,PLOTWE,SUBTITL
      INTEGER TITLE,USEMEAN,USEPOT
      DIMENSION DENN(4),F(50),BETA(5D),GAMMA(50),FF(50),T(50),D(50)
      DATA DENN/.25,.3D,.35,.40/
C     CHECK TO SEE IF DIFTEM IS A CONTINUING ESTIMATE OF TEMPERATURE OF
C     IF IT HAS BEEN REINITIALIZED.
  21D IF(IFIRST) 10,2D,1D
C     CALCULATE SNOWPACK DENSITY, BASED ON TIME OF YEAR.
   2D IF(DATES(1).LT.5) GO TO 3D
      IF(DATES(1).GT.9) GO TO 40
      DEN= .40
      GO TO 5D
   4D DEN= .20
      GO TO 50
   30 DEN=DENN(DATES(1))
C     CALCULATE SNOWPACK DEPTH FROM DENSITY
   50 DEPTH=(PREWEQV/DEN)*2.54
C     CALCULATE DIFFUSIVITY
      DIFUS=(0.01)/((2.751-DEN)*D.48)
C     CALCULATE TAU AND DTAU
      TAU=DIFUS*86400/DEPTH**2
      DTAU=TAU/48
C     DETERMINE THE AVERAGE PACK TEMPERATURE FROM THE EXISTING CALORIE
C     DEFICIT
      PACTEM1=(-CALDEF/(PREWEQV*1.27))+273
C     SET THE INITIAL TEMPERATURE ARRAY AT THE AVERAGE PACK TEMPERATURE
      DO 6D I=1,5D
   6D FF(I)=PACTEM1
      IFIRST=1
   1D RATIO =DTAU/(48.D**2)
      A=-RATIO
      B=1.0+2.D*RATIO
C     CONVERT MINIMUM AIR TEMPERATURE TO DEGREES KELVIN
      TEMPK=((AVETEMF-32.D)*.55555)+273
C     NORMALIZE EXISTING PACK TEMPERATURES
      IF(TEMPK.LE.274.D.AND.TEMPK.GE.272.0) TEMPK = 272.0
    3 DO 7 I=1,50
    7 F(I)=(273-FF(I))/(273-TEMPK)
      DO 4 I=1,49
    4 T(I)=F(I)
      TAU=0.D
C     PERFORM CALCULATIONS OVER SUCCESIVE TIME-STEPS
    5 TAU=TAU+DTAU
      IF(TAU.GT.48*DTAU) GO TO 1DD
C     SET BOUNDARY VALUES
      T(2)=D.D
      T(49)=1.D
C     COMPUTE RIGHT-HAND SIDE VECTOR V
      DO 15 I=2,48
   15 D(I)=T(I)
      D(2)=D(2)+RATIO*T(1)
      D(48)=D(48)+RATIO*T(49)
C     COMPUTE NEW TEMPERATURES
C     COMPUTE INTERMEDATE ARRAYS BETA AND GAMMA
      BETA(2)=B(2)
      GAMMA(2)=D(2)/BETA(2)
      DO 6 I=3,48
      BETA(I)=B-A**2/BETA(I-1)
    6 GAMMA(I)=(D(I)-A*GAMMA(I-1))/BETA(I)
C     COMPUTE FINAL SOLUTION VECTOR T
      T(48)=GAMMA(48)
      DO 11 K=1,46
      I=48-K
   11 T(I)=GAMMA(I)-A*T(I+1)/BETA(I)
      DO 8 I=1,49
    8 F(I)=T(I)
      GO TO 5
  1DD DO 110 I=1,49
  11D FF(I)=-F(I)*(273-TEMPK) +273
      TOT=D.0
C     ESTABLISH AN ARRAY OF FINAL PACK TEMPERATURES TO BE USED IN STAR
C     THE CALCULATIONS OF PACK TEMPERATURES FOR THE NEXT DAY
      DO 8D I=1,MP1
   8D TOT=TOT+FF(I) -273
C     DETERMINE THE CALORIE DEFICIT AND NEW AVERAGE PACK TEMPERATURE
      AV=TOT/MP1
      CALDEF=-AV*(PREWEQV*1.27)
      PACKTEM=AV
      IF(CALDEF) 9D,9D,95
   90 PACKTEM = 0.0
      CALDEF= 0.0
   95 RETURN
      END
```

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A modification of a previously developed computer model of snowmelt provides for modeling intermittent snowpacks, and is believed to be a more generalized model than the original program. The modified program SNOWMELT is dependent on four daily input variables, maximum and minimum temperatures, precipitation, and shortwave radiation or percent cloud cover. Initializing the model requires limited knowledge of local watershed and snowpack parameters. Model verification on seven experimental watersheds in Arizona proved satisfactory.

Keywords: Computer models, intermittent snowpacks, simulation analysis, snowmelt.

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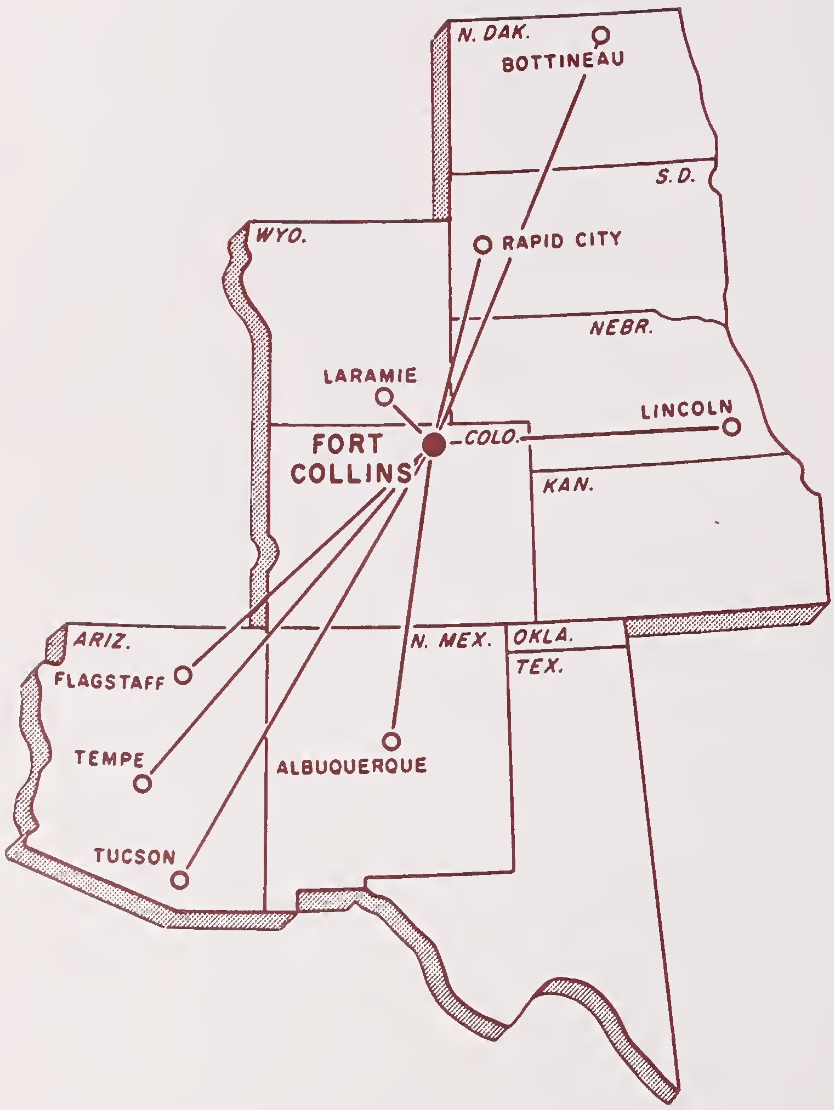
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